Stern Flow Stabilisation to Improve Directional Stability of Tugs with Low Length-to-Beam Ratios

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SYNOPSIS

The trend towards compact, high power ship-handling and escort tugs is pushing naval architects to design hulls with lower length-to-beam (L/B) ratios. Hydrodynamic design with low L/B ratios to achieve good directional controllability while running free can be challenging, particularly for tractor tugs. Flow separation at unavoidably bluff sterns can cause directional instabilities from vortex shedding and the fluctuating yaw moments that accompany it. This is known as vortex induced motion (VIM). These instabilities can be reduced by adding larger skegs aft; however, this is only effective while running ahead. Larger skegs can have a destabilising effect when running astern, and also have the potential to interfere with thruster wash. Astern performance is particularly important for Advanced Voith Tractor (AVT) tugs, which are designed to carry out escort operations while running astern at speeds of up to 12 knots.

This paper discusses state-of-the-art computational fluid dynamics (CFD) and model testing techniques that have been developed to evaluate the directional stability response of low L/B tractor tugs to vortex induced motion. These techniques have been used to develop novel devices called StRAke stabilisers, which substantially improve directional controllability by controlling flow separation at the stern with a minimal increase in drag and no increase in skeg size.

StRAke stabilisers (referred to as StRAkes hereafter) have been successfully installed and tested on the new TRAktor 3000-V and the TRAktor 3200-V, both of which are high performance AVT tugs designed for ship-handling duties in harbour and escort duties at sea. Both tugs are under 500grt and are nominally capable of generating 70 tonnes of bollard pull and 100 tonnes of escort steering force at 10 knots.

INTRODUCTION

Table 1 shows the particulars and L/B ratios for several Robert Allan Ltd-designed Advanced Voith TRAktor (AVT) tugs since 2005, all with similar engine power of approximately 2 x 2,600kW and nominally capable of 70 tonnes of bollard pull. Earlier designs such as the TRAktor 3800-V and TRAktor 3700-V are approximately 36-38m in length, with an L/B ratio of 2.5. They are well over 500grt. This larger size is ideal in terms of hydrodynamic performance for an AVT escort tug with 70 tonnes of bollard pull.

However, the newest designs are truly high performance in the sense that they achieve much of the performance of the larger tugs (still nominally 70 tonnes of bollard pull) but are under 500grt. Accommodating the weight of machinery, particularly Voith 32R5/265-2 thrusters with a combined weight of 120 tonnes, and providing sufficient stability for escort operations is challenging for a tug under 500grt and no more than 32m in length. This inevitably leads to lower L/B ratios and fuller hull forms, as demonstrated by the TRAktor 3000-V, with a waterline length of 28.7m and an L/B

Class	Design Year	GRT	Length WL (m)	Beam (m)	L/B
TRAktor 3000-V	2014	496	28.7	13.0	2.21
TRAktor 3200-V	2013	497	30.0	12.8	2.34
TRAktor 3700-V	2005	692	34.2	13.6	2.52
TRAktor 3800-V	2008	840	34.9	14.0	2.50

Table 1: Robert Allan Ltd AVT Tugs with 70 tonnes nominal bollard pull

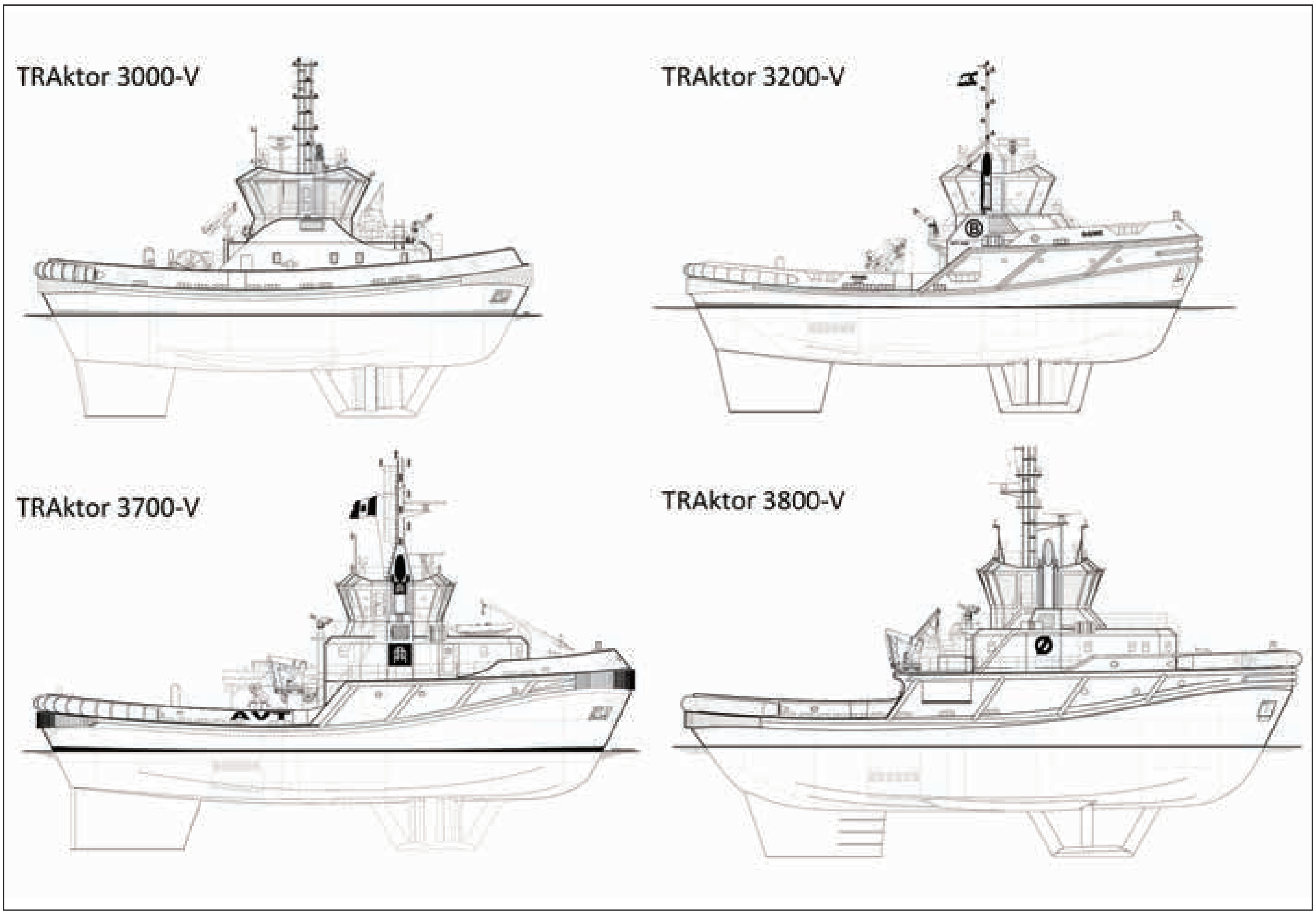

Figure 1: Profile views of TRAktor 3000-V, 3200-V, 3700-V and 3800-V

ratio of 2.21. The TRAktor 3200-V is slightly longer at 30m with an L/B ratio of 2.34 *(Figure 1)*.

The TRAktor hull forms have rounded sterns with a single chine near the vessel baseline (the TRAktor 3800-V stern has two chines). A skeg is fitted aft under the stern and arranged for indirect escort steering operations while running astern. One major advantage of escorting over the stern is that the aft deck, and thus the towing staple position, are lower, which reduces the towline's heeling moment. However, the aft hull waterlines must be rounded to accommodate speeds in excess of 12 knots without swamping, as would occur with a transom stern.

The rounded stern shape approximates a bluff body which is susceptible to flow separation and vortex shedding while running ahead. The stern shape must be fuller with more aggressive waterline curvature to provide the necessary displacement on the TRAktor 3000-V and TRAktor 3200-V compared to the larger AVTs, which have gentler waterline curvature. This increases the propensity for flow separation and vortex shedding – this can be compared to the classic Von Karman vortex street where swirling vortices are shed alternatingly from side to side behind a cylinder *(see Figure 2)*. The stern geometry of an AVT tug is clearly more complicated than a cylinder, but similar principles apply, albeit at much larger size and time scales. Vortex shedding and yaw oscillation periods are slow, typically of the order of 10 to 20 seconds.

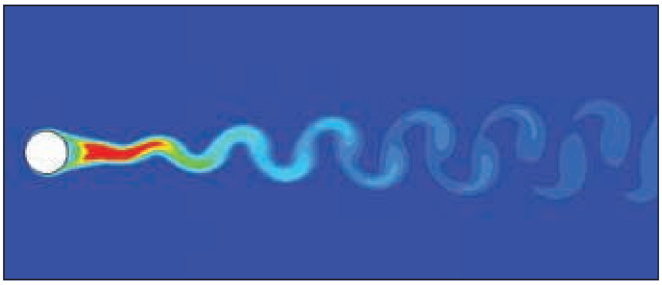

Figure 2: Von Karman vortex shedding from a cylinder

Figure 3: Yaw oscillations (vortex induced motion) without StRAkes

The propensity of a low L/B AVT hull to shed vortices is difficult to predict. Very minor changes in stern geometry can affect the flow separation position and either eliminate or exacerbate vortex shedding and oscillating yaw moments. *Figure 3* shows the stern

wake of the TRAktor 3000-V without StRAkes while running ahead at 12 knots; the steering controls are hands off and the auto-pilot is disengaged. While this oscillation can be corrected with the autopilot, some manoeuvres (ship-handling, escorting) require hand steering, which becomes more difficult with yaw oscillations.

Figure 4 shows the TRAktor 3000-V in a detailed view of the stern with StRAkes.

Figure 4: TRAktor 3000-V showing StRAke stabilisers on the stern

MODEL TESTING

Robert Allan Ltd and Voith Turbo collaborated on an extensive research and development programme in 2016 to tackle the issue of yaw oscillations on low L/B ratio tugs. Extensive testing of over 50 stern and appendage configurations was carried out on the TRAktor 3000-V model at the Voith flume tank in Heidenheim, Germany. Robert Allan Ltd carried out a computational fluid dynamics (CFD) programme in parallel with the Voith flume tank testing, with the support of the National Research Council of Canada's Industrial Research Assistance Program (IRAP). The purpose of the CFD programme was to duplicate the Voith flume tank results and develop a screening method that could be easily applied to predict yaw oscillations on any tractor tug design without model testing.

Figure 5 shows the TRAktor 3000-V in the Voith flume tank. The model is towed by a short tow rod mounted on the bow. This allows the model to yaw and sway in response to hydrodynamic fluctuations at the stern. This arrangement is not self-propelled and therefore does not directly mimic a real vessel running free under its own power. However, the arrangement is convenient for rapidly testing various stern and appendage configurations. It has also been shown that if yaw oscillations can be damped in the flume tank, as occurred for the TRAktor 3000-V when the StRAkes were added, then the damping at full scale on sea trials will be even more effective. The tow rod appears to exaggerate any yaw instabilities that may be present, which makes this test method conservative.

Following the Voith flume testing, additional tests were carried out at the Vienna Model Basin in calm water, also with IRAP support *(see Figure 6)*. This was necessary to confirm that the turbulence in the flume tank and the proximity of the side walls were not influencing the results. Indeed, yaw oscillations were observed in Vienna Model Basin tests for the bare stern and they were damped out after the StRAkes were added.

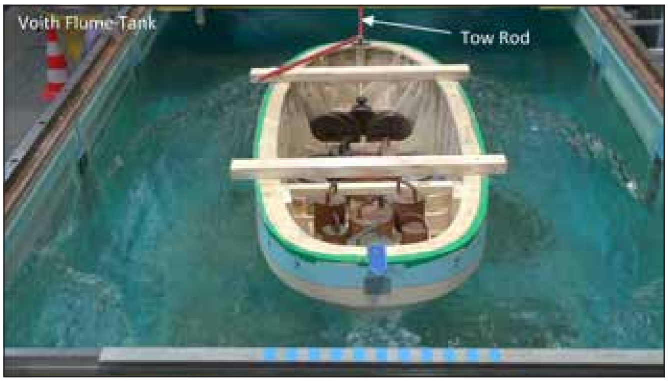

Figure 5: Towed offset tests at Voith Flume Tank TRAktor 3000-V at 12 knots

Figure 6: Towed offset tests at Vienna Model Basin for TRAktor 3000-V at 12 knots

CFD

The computing resources needed for yaw oscillation simulations in CFD are significant. Each simulation contains over 20 million cells and takes approximately 15 hours to run on the Robert Allan Ltd High Performance Cluster (HPC) with 480 processor cores at 3.0GHz.

The CFD simulations use a similar test configuration to the Voith flume tank and the Vienna Model Basin tests; however, they are run at full scale, not model scale *(see Figure 7)*.

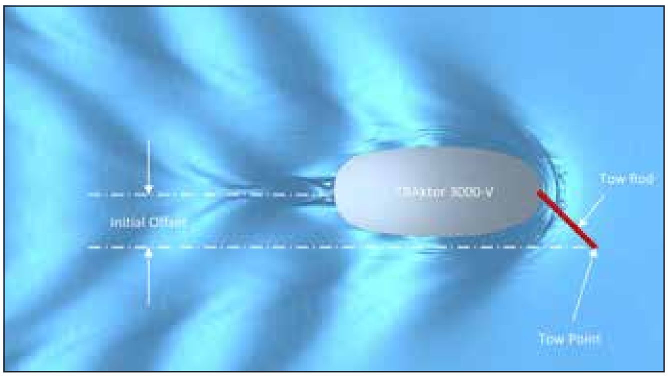

Figure 7: CFD towed offset tests

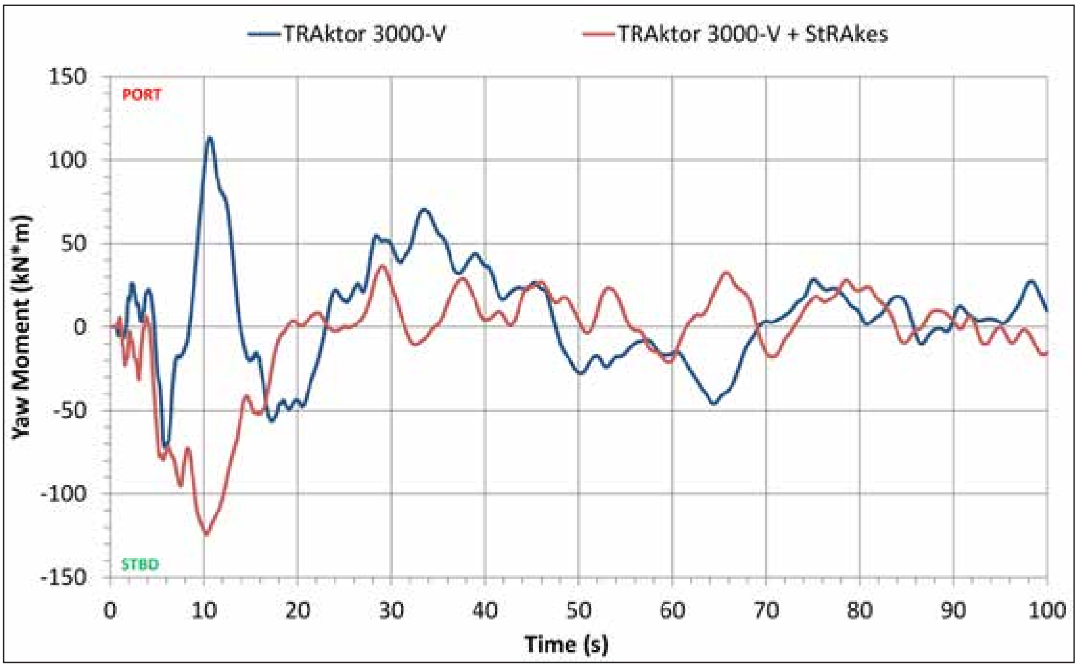

Figure 8: Yaw moment fluctuations while towed ahead at 12 knots with motion constrained

Initially, the tug is held in a fixed position. The yaw moments during the first 100 seconds in this fixed position are given in *Figure 8* for the TRAktor 3000-V with a bare stern and with the StRAkes fitted. The yaw moment is unsteady due to flow separation and vortex shedding at the stern. The unsteadiness is not particularly clean or periodic, but this is expected given the complex geometry of the stern.

When the tug is towed straight ahead with yaw and sway motion released (ie, without an initial yaw offset), it can take a considerable time for the yaw oscillations to develop. Rather than wait for the yaw oscillations to build naturally, an initial yaw excitation is artificially applied with a 45 degree offset to the tow rod. When motion is released from this position, the hull immediately yaws towards the tow point, thereby generating a yaw excitation. If the hull can damp an artificially applied yaw excitation, it should also be able to damp the much smaller yaw excitations generated by vortex shedding.

The concept of the StRAkes is illustrated in *Figure 9*. The top image shows the bare stern of the TRAktor 3000-V while sailing ahead at 12 knots with yaw and sway constrained. The bottom figure shows the same with StRAkes added. The StRAkes are half pipes, 300mm in diameter, that have been carefully located just forward of the natural flow separation point. The dashed white line indicates the flow separation point and the black line indicates the position of the StRAkes (as installed in the lower part of the figure). The flow streamlines and relative pressure are also shown where the relative pressure is the difference between the local pressure and the hydrostatic pressure. This removes hydrostatic pressure to make the hydrodynamic effects more visible.

Flow separation occurs at the StRAkes, resulting in a slightly lower pressure (yellow) on the stern at the centreline compared to higher pressure (orange) without StRAkes. This increases the vessel's drag by about 5 per cent at 12 knots.

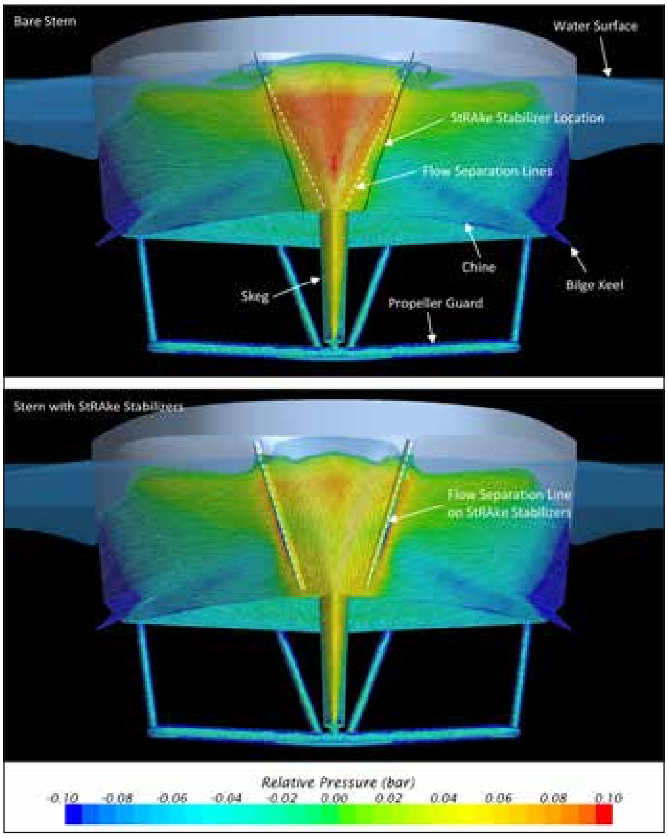

Figure 9: Stern pressure and streamlines for TRAktor 3000-V, constrained ahead at 12 knots

The yaw response of the TRAktor 3000-V when released from an initial tow rod offset of 45 degrees is given in *Figure 10*. From the initial offset, both configurations immediately yaw to starboard. For the TRAktor 3000-V with StRAkes, the yaw oscillations quickly damp out from an initial amplitude of 10 degrees down to about 1 degree. Without StRAkes, the yaw motions do not damp out and continue with an amplitude of approximately 9 degrees. The simulation

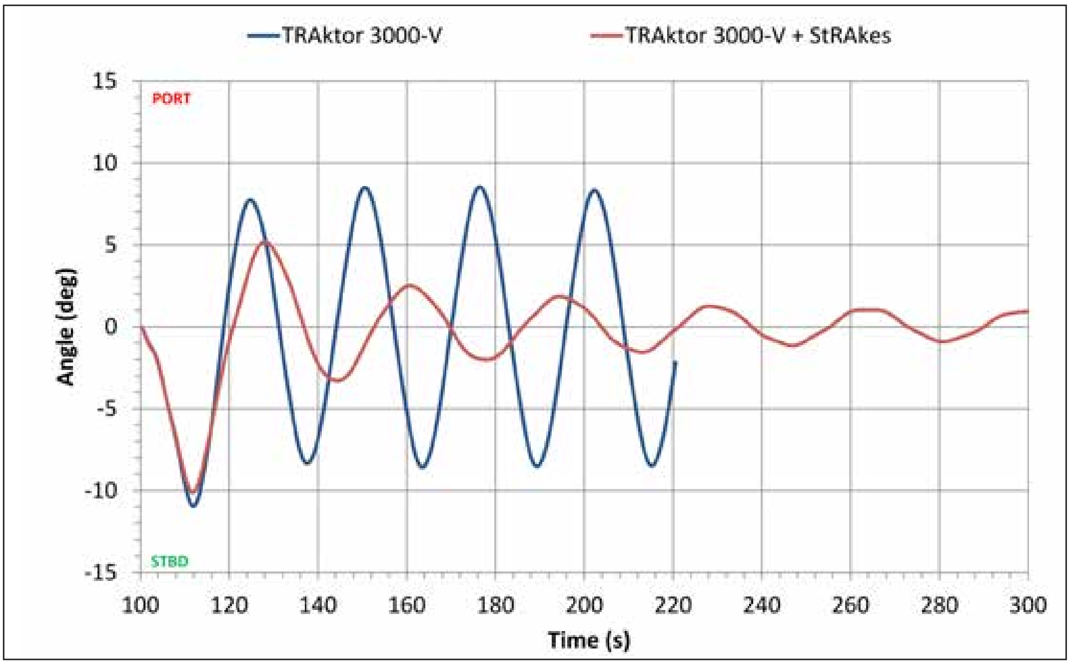

Figure 10: Yaw angle in 45-degree towed offset test at 12 knots

was stopped at 220 seconds since there was no sign the yaw oscillations would damp after that.

Figure 12, overleaf, shows a series of water surface images of the TRAktor 3000-V with a bare stern (left) and with StRAkes (right) in the towed offset test as plotted in *Figure 10*. Towed offset motion is released at 100 seconds; time is shown in the upper right corner of each image and the tow rod is shown in red. The images run from 100 to 130 seconds, since the main differences with and without StRAkes can be seen in that time frame.

The pressure distribution, streamlines and flow separation points are shown in *Figure 13*, again without StRAkes on the left and with StRAkes on the right. At 115 seconds, TRAktor 3000-V has finished the first yaw movement to starboard and is beginning to yaw to port. Without StRAkes, the flow separation point on the starboard side of the stern has moved aft of where the StRAke would be located (black line) and is generating a low pressure area (blue-green) on the starboard side of the stern. Conversely, the flow separation point has moved forward on the port side, generating a high pressure region there (red-orange). This pressure differential results in a transverse force that pushes the stern to starboard, thereby accelerating the port yawing motion.

At 125 seconds, the opposite occurs; the vessel is beginning to yaw to starboard. The flow separation point has moved aft of the StRAke position on the port side and has moved forward on the starboard side, again generating a transverse pressure differential across the stern that tends to move the stern to port and augment the yaw motion to starboard.

The stern with StRAkes, on the other hand, does not show any movement in the flow separation point nor is there a significant variation in the pressure distribution between port and starboard. This is because the StRAkes fix the flow separation position. There are minor pressure variations in between the StRAkes but this is not important since there is virtually no longitudinal hull surface there (ie, the pressure variations cannot generate forces in the transverse direction and therefore cannot generate a yawing moment).

The StRAkes do not prevent flow separation and vortex shedding but instead confine these phenomena to a fixed area where they cannot generate destabilising yaw moments.

Three dimensional renderings of the stern vortices are shown in *Figure 14*. The red areas indicate high vorticity and show that there are four major vortices. There are two big vortices, port and starboard, generated by flow around the bottom chines which curves upwards along the hull. These vortices influence the flow behaviour in the lower part of the stern. The second set of vortices is generated by the bilge keels and trail aft to influence the flow at the upper part of the stern. Both sets of vortices are present with and without the StRAkes. Indeed, the StRAkes do not prevent vortex generation but they do influence how the vortices interact with the flow at the stern by controlling the position of flow separation.

The effectiveness of the StRAkes at full scale on the TRAktor 3000-V is nicely demonstrated by the straight wake pattern in *Figure 11* – compare this with the wake pattern in *Figure 3*.

Figure 11: TRAktor 3000-V at 12 knots with StRAkes

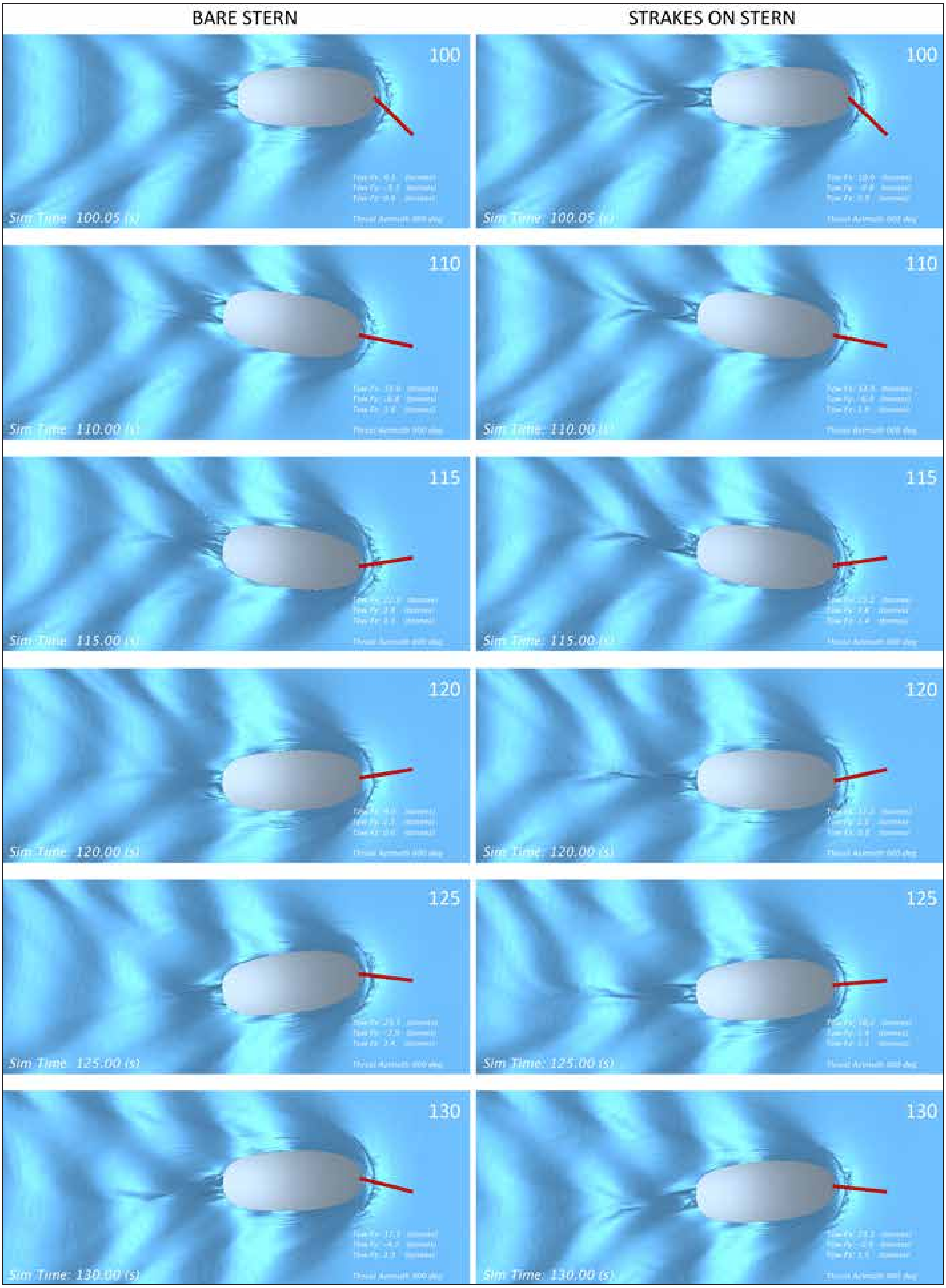

Figure 12: Water surface in TRAktor 3000-V towed offset test at 12 knots, tow rod in red

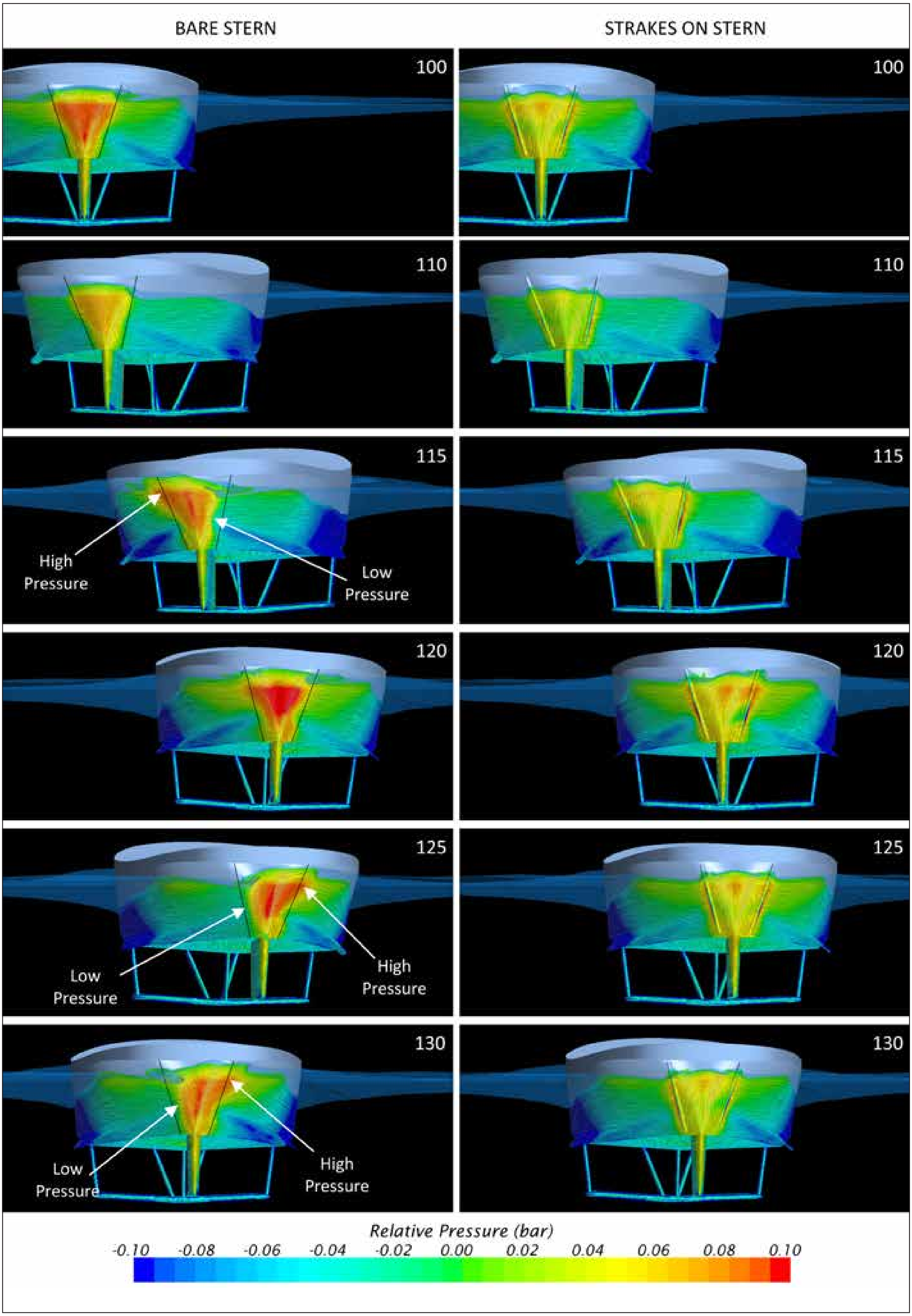

Figure 13: Stern relative pressure in TRAktor 3000-V towed offset test at 12 knots

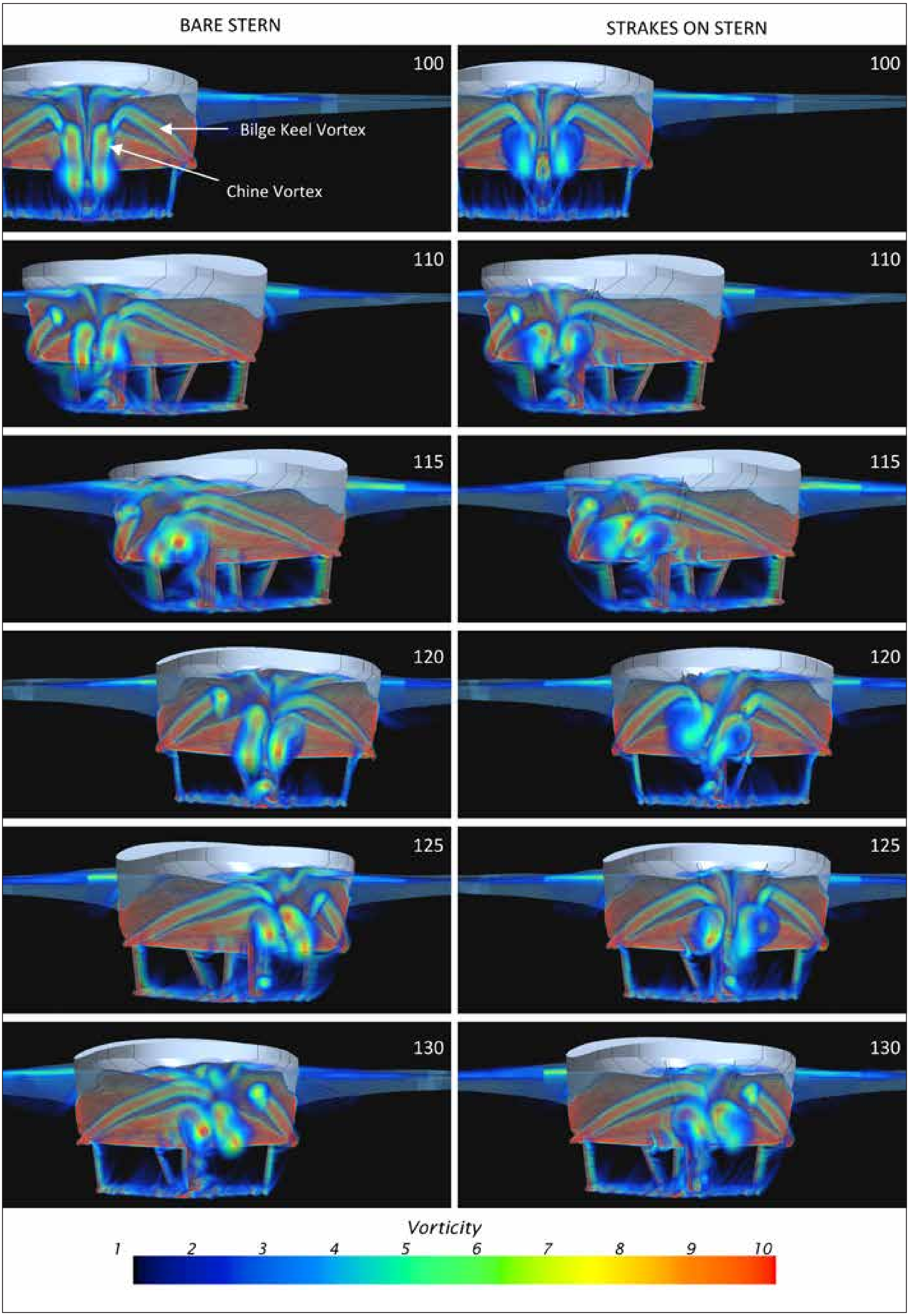

Figure 14: Stern vorticity in TRAktor 3000-V towed offset test at 12 knots

CONCLUSION

Through an extensive CFD and model test programme, Robert Allan Ltd and Voith have developed a novel method for improving the directional controllability characteristics of AVT tugs with low L/B ratios.

Fuller hull forms with more aggressive waterline curvature aft are a result of providing the necessary displacement and stability (ie, beam) for escort operations without exceeding 500grt. A side effect of these bluffer hull forms is flow separation and vortex shedding at the stern. These phenomena can generate yaw moment excitations which are exacerbated by the flow separation point moving fore and aft to different positions on either side of the stern. This can generate an alternating pressure differential between the port and starboard sides of the stern and result in a self-sustaining yaw oscillation.

StRAke stabilisers are 300mm half pipes installed on the stern just forward of the natural flow separation point. The StRAke stabilisers do not prevent vortex shedding but instead fix the flow separation point to limit the pressure differences on either side of the stern that generate an oscillating yaw moment. The location of the StRAke stabilisers is critical and must be determined by CFD or model testing.

The recently patented StRAke stabilisers are an innovative solution for AVT tugs that run astern at high speeds during escort operations. They may also be applied effectively to Z-drive tractor tugs. Indeed, StRAke stabilisers are allowing low L/B ratio AVT tugs to push boundaries of performance that were until very recently reserved for tugs well over 500grt.